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OSTEOLOGIC STUDIES FOR DETERMINING THE SKELETAL QUALITY OF CADAVERS USED IN CRASH TESTING

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ABSTRACT

Osteologic studies, performed on the ribs, femora and radii of cadavers used for crash testing experiments are described. Two techniques are presented which are performed on ribs post-test, and two techniques are presented which are performed on long bones as pre-test methods. Comparisons of the results of the four techniques when used on the same cadavers are given. It is concluded that a viable technique exists for determining the level of osteopenia in flat bones after a crash test. It is further concluded that a method also exists for determining skeletal quality prior to a crash test without adversely affecting the subject's usability.

Note 1: The views, findings and opinions reflected in this paper are those of Calspan Corporation and do not necessarily reflect the official views of the Department of Transportation, National Highway Traffic Safety Administration.

Note 2: The work reported herein, with respect to cadavers, conforms to the guidelines of the American Association of Physical Antropologists (1975), "Resolution Concerning Ethical Position on the Use of Human Bodies in Research".

INTRODUCTION

A major concern in evaluating results of crash tests with cadavers is that of comparability or relative quality of the subjects. Therefore, in addition to the obvious parameters used for definition in cadaver research (such as age, height, weight, cause of death, etc.) there is a need for additional specificity with regard to strength characteristics of bones. The criterion most commonly used by researchers in measuring quality is skeletal strength, as determined by a "beam bending" test of one of the subject's ribs.

A common malady in the aged or those confined to bed for long durations is osteoporosis (porous bone). Since most cadavers available for research are of advanced age, or have been confined to bed, the question of the level of osteoporosis in a given subject must be one of the primary considerations in cadaver selection. Osteoporosis, early in its development, is most notable in the lumbar vertebrae, and a trained orthopedist or radiologist can, to some degree, detect and define the level of bone deterioration from x-rays taken prior to selection. Unfortunately, such expertise or equipment is not always available to researchers at the time selection must be made. Further, an absence of a high level of osteoporosity in the lumbar region does not preclude the possibility of an objectionable level of osteopenia (bone deficiency) since the loss of existing bone or a failure to form bone cannot be reliably determined from a single radiograph (Reference 1). Finally, a high level of osteoporosis in the lumbar region does not preclude the possibility of normal bones in the thoracic region and upper extremities (as could occur in the case of an otherwise functional wheelchair patient).

Regardless, determination of the condition of the skeletal quality of a candidate cadaver, with respect to osteoporosis/osteopenia, is of utmost importance in selection or rejection for crash testing. Knowledge of the presence or absence of either could help determine the type of exposure (i.e., whole body concentrated loading, whole body distributed loading, or component testing) for which the subject is best suited.

Therefore, alternate techniques of bone quality determination are being considered. It is the purpose of this paper to describe four osteologic techniques (both pre-test and post-test) which are usable for determination of the skeletal quality of cadavers used in crash test environments. Any method utilizing ribs taken during the autopsy is a post-test, or an after-the-fact, evaluation of skeletal quality. More useful are pre-test methods, which are a before-the-fact evaluation of skeletal quality.

Techniques to be described and discussed in this paper are (1) Garn, Poznanski and Nagy (Reference 1), (2), a variation of this method which is performed on the subject's radius, (3) Epker and Frost (Reference 2) and (4) Granik and Stein (Reference 3).

DISCUSSION

Pre-Crash Test Evaluation Methods

Garn, Poznanski and Nagy have reported work based upon x-ray studies of the second metacarple. This technique assumed that the metacarple (a long bone) has a hollow cylindrical cross-section at the mid-point of its length. Using vernier caliper measurements taken from the x-ray of the subperiosteal width and the medullary width a percent cortical area (PCA) was derived. The normal subject values of PCA reported were based upon measurements taken from more than 2000 clinically healthy in-vivo subjects and were delineated according to age and sex.

Radiographic Long Bone Test

Pre-test x-rays do not usually include the hands of the cadaver. However, long bones have similar characteristics in that the medullary cavity tends to narrow and cortical area tends to maximize near the mid shaft. While it is understood that long bones, such as femurs, are affected by such variables as body weight, habitus, etc., it was felt that they might be a reasonable

indicator of overall bone quality for these osteologic studies. As Garn et al pointed out, evaluation of this type should be undertaken with caution since studies show that a reliable judgment of bone loss cannot be made on the basis of a single radiograph unless a considerable amount of bone loss has taken place.

Experimental Technique

Measurements were made near mid shaft, of the total diameter and medullary diameters from the x-rays of the subjects femurs. X-rays of both femurs in the anterior-posterior (A-P) direction were used.

Data Analysis

The femur PCA was calculated using the equation

$$PCA = 100\ (T^2 - M^2)/T^2$$

where T = total diameter and (in.)

M = medullary diameter (in.)

Data are presented in Table 1 for twelve cadavers used in crash tests at Calspan. For purposes of identification cadavers are serially designated as Calman 6, 8, etc. Radiographic femur data were not available for Calman 7 and 9.

Calspan Radius Test

It was reasoned that if Garn et al could determine the percent cortical area from a radiograph of a long bone (using the assumption that the bone is a hollow circular cylinder) and from this data delineate normal subjects from those with bone abnormalities, then a scheme wherein the PCA is determined from the actual cross section of an easily excisable long bone should be pursued as an accurate pre-test determination of bone quality for cadaver research.

TABLE 1

RADIOLOGICAL LONG BONE DATA

Calman	Left Femur		Right Femur		Average PCA
	T	M	T	M	
6	1.25	.57	1.27	.60	78.5
8	1.47	.82	1.47	.78	70.4
10	1.49	.60	1.44	.57	84.0
11	1.55	.62	1.49	.65	82.5
12	1.16	.48	1.10	.45	83.1
13	1.28	.92	1.43	.90	54.3
14	1.34	.58	1.32	.72	75.8
15	1.44	.62	1.43	.67	79.7
16	1.29	.62	1.20	.67	72.9
17	1.33	.54	1.30	.52	83.8
18	1.40	.68	1.33	.48	81.7
19	1.34	.58	1.30	.60	80.0

The radius was chosen as the long bone to be used in this study since it is easily excisable and its removal before impact testing does not significantly affect the cadaver's performance. Recently, it has been possible to remove only a section of the radius for study, before selection, and, using a clamp to secure the two remaining parts, have an intact lower arm.

As pointed out above, long bones are affected by habitus. For this work the left radius is used for pre-test evaluation. At autopsy the right radius is removed and the percent cortical area determined.

Experimental Technique

A small section of the radius (approximately one-quarter inch in length) was taken and cleaned in a 0.7 normal saline solution in an ultrasonic cleaner for five minutes. This section was then blown dry with laboratory air, removing the fatty marrow and leaving only the cortical bone.

This section of bone was then photographed under ordinary visible light with a 3.6X magnification. For the earlier subjects (Calman 6-13) this photo was given a 2.78 magnification to create a 10X print. Using this photograph the total area and medullary area were measured using a planimeter.

Details of the bone sample preparation technique required for measurement as well as a description of photographic methods are presented in the section on Granik and Stein Experimental Techniques.

Data Analysis

The percent cortical area was calculated using the equation

$$PCA = 100 \left(\frac{A_t - A_m}{A_t}\right)$$

where A_t = total area

A_m = medullary area

The data presented in Table 2 encompass pre- and post-test measurements. On all subjects, radius samples were sectioned approximately two inches from the proximal end and two inches from the distal end of both right and left radii.

Post-Crash Test Evaluation Methods

Ribs taken from the cadavers at autopsy are used for post-test evaluation of skeletal quality. Two techniques performed on ribs are those reported by Epker and Frost and Granik and Stein. Both methods will be discussed in this section.

Epker and Frost Rib Test

Epker and Frost hypothesized: "From the standpoint of the amount of bone present, all points of a given rib of a person are equally normal or abnormal (it is assumed there is no purely local pathological process in the rib being studied)", and "the remaining ribs are equally normal or abnormal". Their work with 561 cadaver rib cross-sections from 181 metabolically normal individuals and 19 individuals with known chronic illness and osteoporosis was used to develop a "parabolic index" which serves to indicate the degree of osteoporosis in a bone or skeleton. The parabolic index for normal subjects is reported as a function of age.

In this technique it is not necessary to load the rib to fracture or to determine the moment of inertia of the rib cross-section. Only the cortical area, the marrow area and the total cross-section area are required to determine the parabolic index. A normalized age-compensated parabolic index is also suggested.

TABLE 2

CALSPAN RADIUS TEST DATA

Calman	Radius	A_t**	A_m**	PCA	Average PCA
6	Left - distal	2.056	.336	83.7	
8	Left - distal	1.855	.566	69.5	
9	Left - proximal	2.179	.453	79.2	
	distal	2.231	.456	79.6	79.4
10	Left - proximal	1.848	.424	77.1	
	distal	1.766	.403	77.2	77.2
11	Left - distal	2.545	.961	62.2	
12	Right - proximal	1.426	.447	68.7	
	distal	1.235	.245	80.2	
	Left - proximal	1.353	.523	61.3	
	distal	1.117	.161	85.6	74.0
13	Right - proximal	2.298	.943	59.0	
	mid-shaft	2.022	.426	78.9	
	distal	1.855	.570	69.3	
	Left - proximal	2.686	1.201	55.3	
	mid-shaft	1.937	.429	77.8	
	distal	1.649	.539	67.3	67.9
14	Right - proximal	.260	.083	68.1	
	mid-shaft	.235	.047	80.0	
	distal	.246	.077	68.7	
	Left - proximal	.240	.075	68.8	
	mid-shaft	.225	.050	77.8	
	distal	.235	.055	76.6	73.3
15	Right - proximal	.330	.115	65.2	
	mid-shaft	.310	.063	79.7	
	distal	.321	.095	70.4	
	Left - proximal	.340	.108	68.2	
	distal	.296	.083	72.0	71.1
16	Right - proximal	.340	.207	39.0	
	mid-shaft	.334	.166	50.3	
	distal	.390	.165	57.7	
	Left - proximal	.311	.150	51.8	
	mid-shaft	.330	.091	72.4	
	distal	.330	.135	59.1	55.1
17*	Right - proximal	.241	.056	76.8	
	mid-shaft	.262	.020	92.4	
	distal	.260	.042	83.8	
	Left - proximal	.271	.068	74.9	
	distal	.237	.014	94.1	84.4

TABLE 2 (Cont'd)

CALSPAN RADIUS TEST DATA

Calman	Radius		A_t**	A_m**	PCA	Average PCA
18	Right -	proximal	.352	.110	68.7	
		mid-shaft	.324	.072	77.7	
		distal	.408	.148	63.7	
	Left -	proximal	.340	.125	63.2	
		distal	.324	.096	70.3	68.7
19	Right -	proximal	.367	.150	59.1	
		mid-shaft	.300	.069	77.0	
		distal	.322	.105	67.4	
	Left -	proximal	.312	.096	69.2	
		distal	.326	.102	68.7	68.3

*Left radius contained a Rush hooked intramedullary pin.

**A_t and A_m are measured in square inches x 10^{-1}.

Experimental Technique

A small section (approximately one-eighth inch thick) of the rib was obtained and cleaned in 0.7 normal saline solution in an ultrasonic cleaner for five minutes, then blown dry with laboratory air removing the red marrow and leaving only the cortical and cancellous bone. This section of bone was photographed under ordinary visible light with a 3.6X magnification. Photos for the earlier subjects (Calman 6-13) were raised to a 10X magnification.

These photos were measured for total area and medullary area using a planimeter. Parabolic Index is then calculated:

$$PI = \frac{(A_t - A_m) \times A_m}{(A_t^2)}$$

where A_t = total area
A_m = marrow area

A normalized age-compensated parabolic index (K) serves as a way to evaluate and compare the degree of osteoporosis in ribs from different persons regardless of body habitus, sex, age or disease. It is calculated using the equation:

$$K = PI \left[4 \left(\frac{265 + |\gamma|}{265}\right)\right]$$

where $|\gamma|$ = the absolute value in years minus 20

Data Analysis

Table 3 contains the parabolic indices obtained from ribs 5, 6 and 7 (either right or left) on all subjects, discussed in this paper.

TABLE 3

EPKER AND FROST RIB TEST DATA

Calman	Rib	A_t*	A_m*	PI	Avg. PI	Age	K
6	5	1.137	.849	.189		57	.86
7	5	.715	.323	.251		70	1.19
8	5	1.220	.945	.175	.201	51	.90
	6	1.373	.904	.225			
	7	1.504	1.080	.202			
9	6	1.068	.729	.217	.228	56	1.04
	7	.885	.534	.239			
10	6	1.052	.682	.228	.209	67	.99
	7	.920	.686	.190			
11	5	1.405	.933	.223	.228	62	1.05
	6	1.013	.672	.223			
	7	1.628	1.053	.238			
12	5	.525	.265	.250	.248	65	1.10
	6	.507	.262	.250			
	7	.638	.268	.244			
13	5	.791	.403	.250	.240	17	.97
	6	.747	.257	.226			
	7	.869	.371	.245			
14	5	.123	.090	.196	.229	60	1.05
	6	.126	.070	.247			
	7	.155	.090	.243			
15	5	.127	.074	.243	.237	63	1.10
	6	.128	.078	.238			
	7	.137	.088	.230			
16	5	.186	.140	.186	.185	61	.85
	6	.209	.159	.182			
	7	.200	.150	.188			
17	5	.142	.077	.248	.246	27	1.01
	6	.166	.096	.244			
	7	.177	.100	.246			
18	5	.134	.061	.248	.246	57	1.12
	6	.150	.090	.240			
	7	.146	.076	.250			
19	5	.164	.104	.232	.232	61	1.07
	6	.177	.105	.241			
	7	.208	.139	.222			

*A_t and A_m are measured in square inches x 10^{-1}.

Granik and Stein Rib Test

The Granik and Stein technique requires that either the sixth or seventh rib, taken between the anatomical mid-clavicular and posterior axillary line be subjected to a load to fracture test wherein the rib is supported on a four inch span and loaded at the mid point of the span. The force-deflection history is recorded to failure and the rib is then sectioned and photographed.

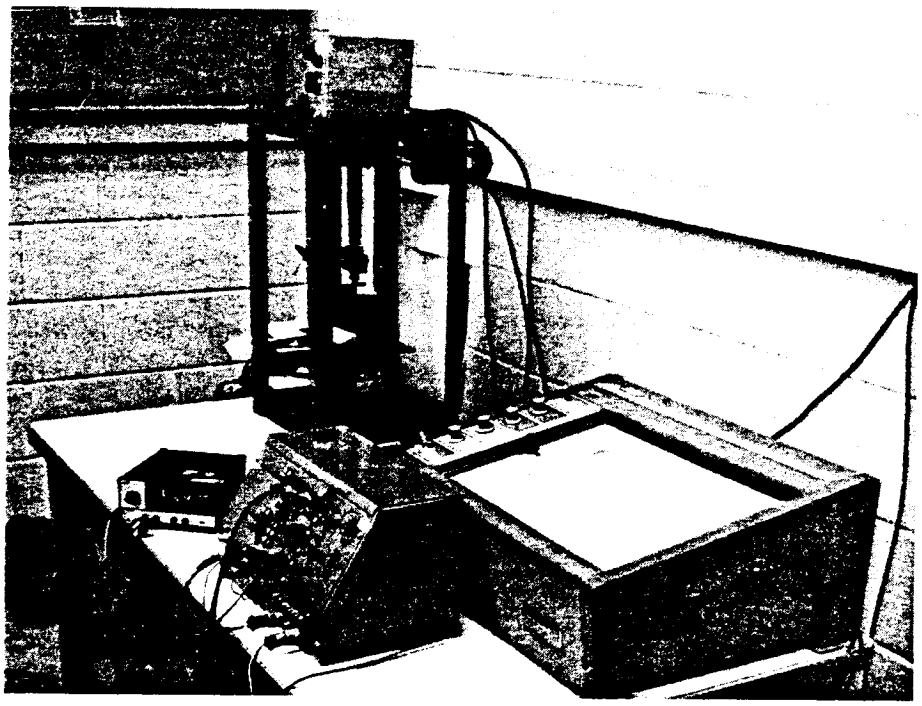
The moment of inertia for the cortical cross section is determined and the modulus of elasticity and stress at failure are calculated. Granik and Stein did not report the modulus nor the stress at failure of their ten subjects as a function of age.

Experimental Technique

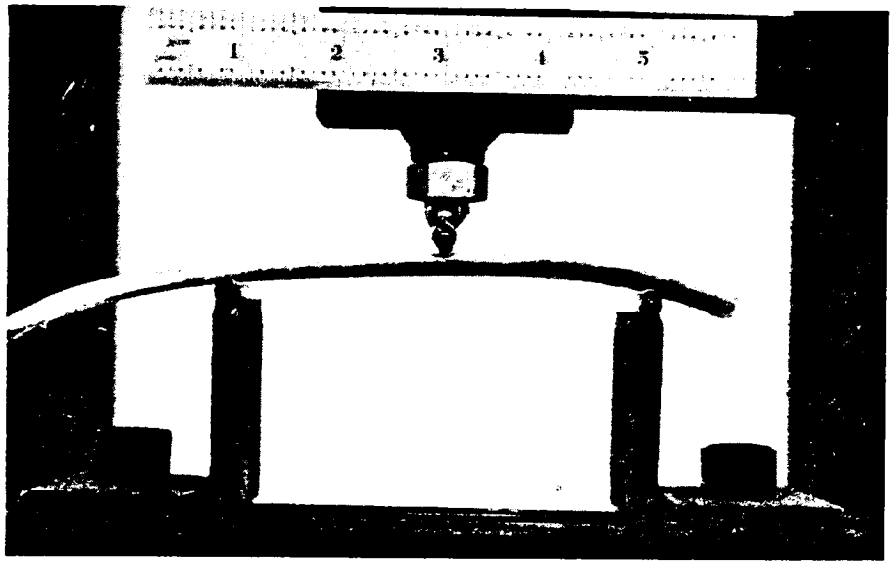
A loading device (Figure 1) was fabricated to load the bone at 0.1 inch per minute while measuring the force. The displacement was measured by a wire wound linear potentiometer (6-1/2 inches Bourns) while the force was being measured by a load cell (BLHU3G1). These two signals were used to drive the recording pen of an x-y plotter (PACE) in the y and x directions, respectively. Figure 2 is a typical force-deflection trace of a rib under test.

Visualizing the cortical (hard) bone presented a large problem. Granik and Stein reported that the rib should be sectioned at the point of fracture and photographed under ultraviolet illumination. Their subsequent photographic print, with a ten times enlargement, then was used for determination of the moment of inertia of the cross section.

The purpose of the ultraviolet illumination is to allow differentiation between the cortical bone, the cancellous bone and the red marrow, since the bone will fluoresce when illuminated by ultraviolet light and the red



LOADING DEVICE WITH PLOTTER AND CALIBRATION EQUIPMENT



LOADING PLUNGER AND REACTIVE SUPPORTS

Figure 1 LOADING DEVICE

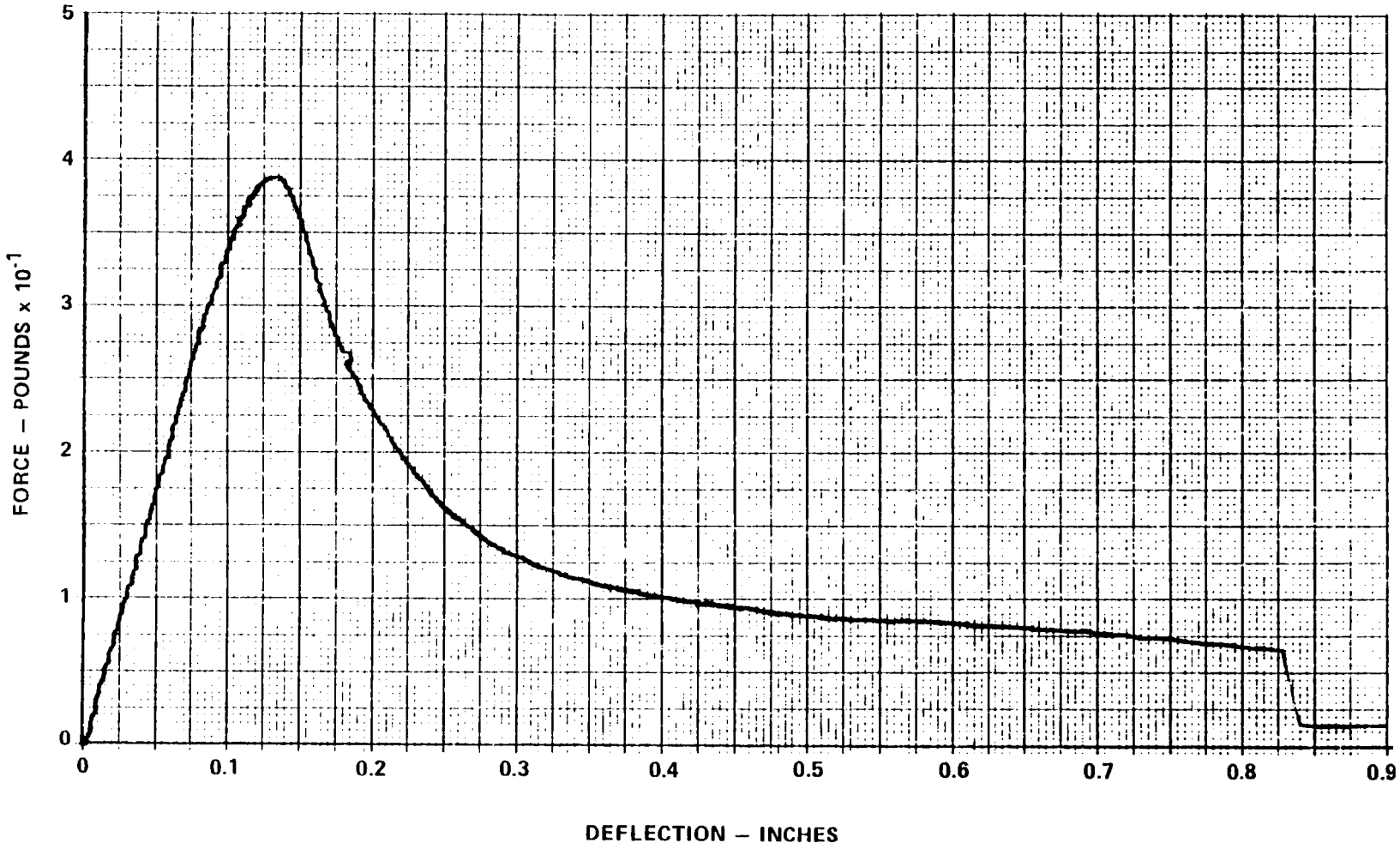


Figure 2 TYPICAL FORCE–DEFLECTION GRAPH FOR RIB

marrow will not. Care must be exercised in using this technique since (without going into the physical principles involved), if the reflected ultraviolet light (which is much more energetic than the visible fluorescent light) is not filtered out before entering the camera it will over-expose the areas from which it is reflected and abrogate the scheme. Figure 3 shows the same rib section under both illumination conditions. A filter such as a Kodak Wratten Number 2B filter placed over the lens is sufficient to eliminate the reflected ultraviolet light.

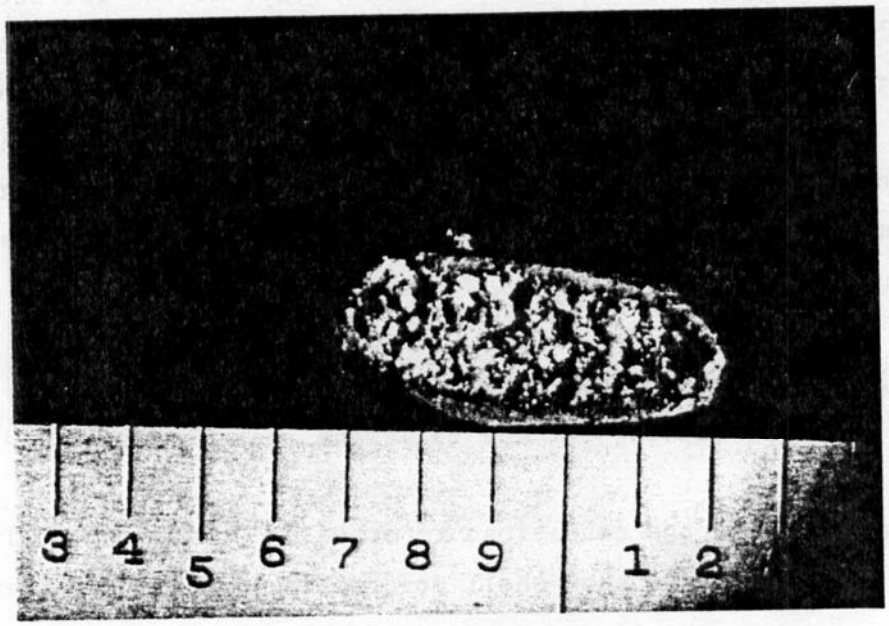
In the work reported here, it has not been possible to section the rib at the point of loading for the following reasons (Figures 4 and 5):

(1) Unlike the conditions reported by Granik and Stein, the loaded cortex did show shell deformation under the loading point, and

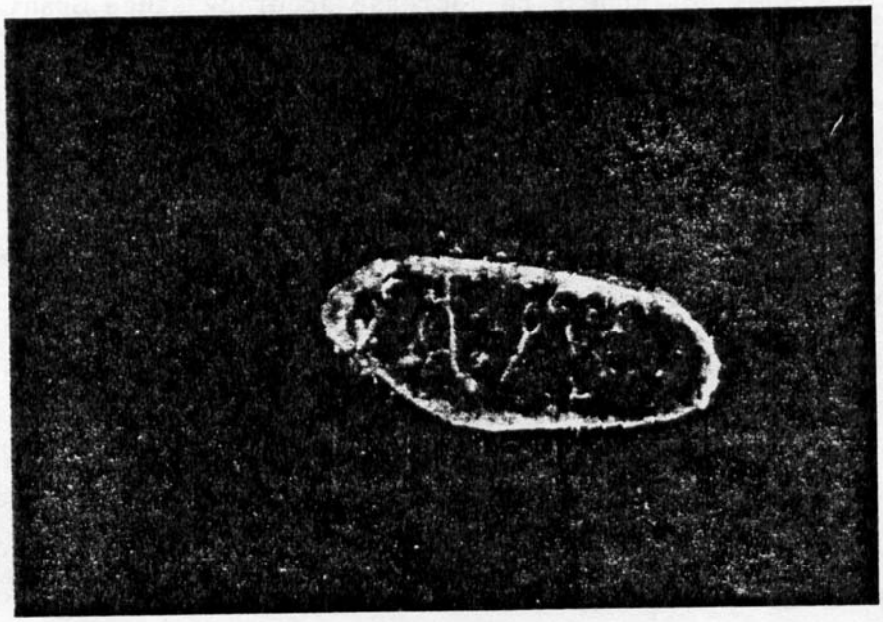
(2) The mode of fracture removed some of the cortical bone which would then not be in the photograph for analysis.

This does not appear to decrease accuracy since Granik and Stein also reported that the value of the moment of inertia did not vary significantly along the rib. Even with the properly filtered ultraviolet illumination, the cortical bone is difficult, at best, to differentiate.

If a small section (approximately one-eighth inch thick) of the rib is taken near the point of fracture and cleaned in 0.7 normal saline in an ultrasonic cleaner for five minutes, then blown dry with laboratory air, the red marrow is removed leaving only the cortical and cancelllous bone. This section of bone can be photographed under ordinary visible light with better definition than the uncleaned sections under filtered ultraviolet illumination. Figure 6 displays a comparison of an uncleaned and a cleaned section of a rib photographed under the three types of illumination discussed above. The surfaces shown are surfaces from the same saw cut, i.e., they are mirror images.



RIB SECTION-ULTRA-VIOLET LIGHT SCALE DIVISIONS .100 INCHES



RIB SECTION-ULTRA-VIOLET LIGHT WITH 2B FILTER

Figure 3 FILTERED AND UNFILTERED ILLUMINATION

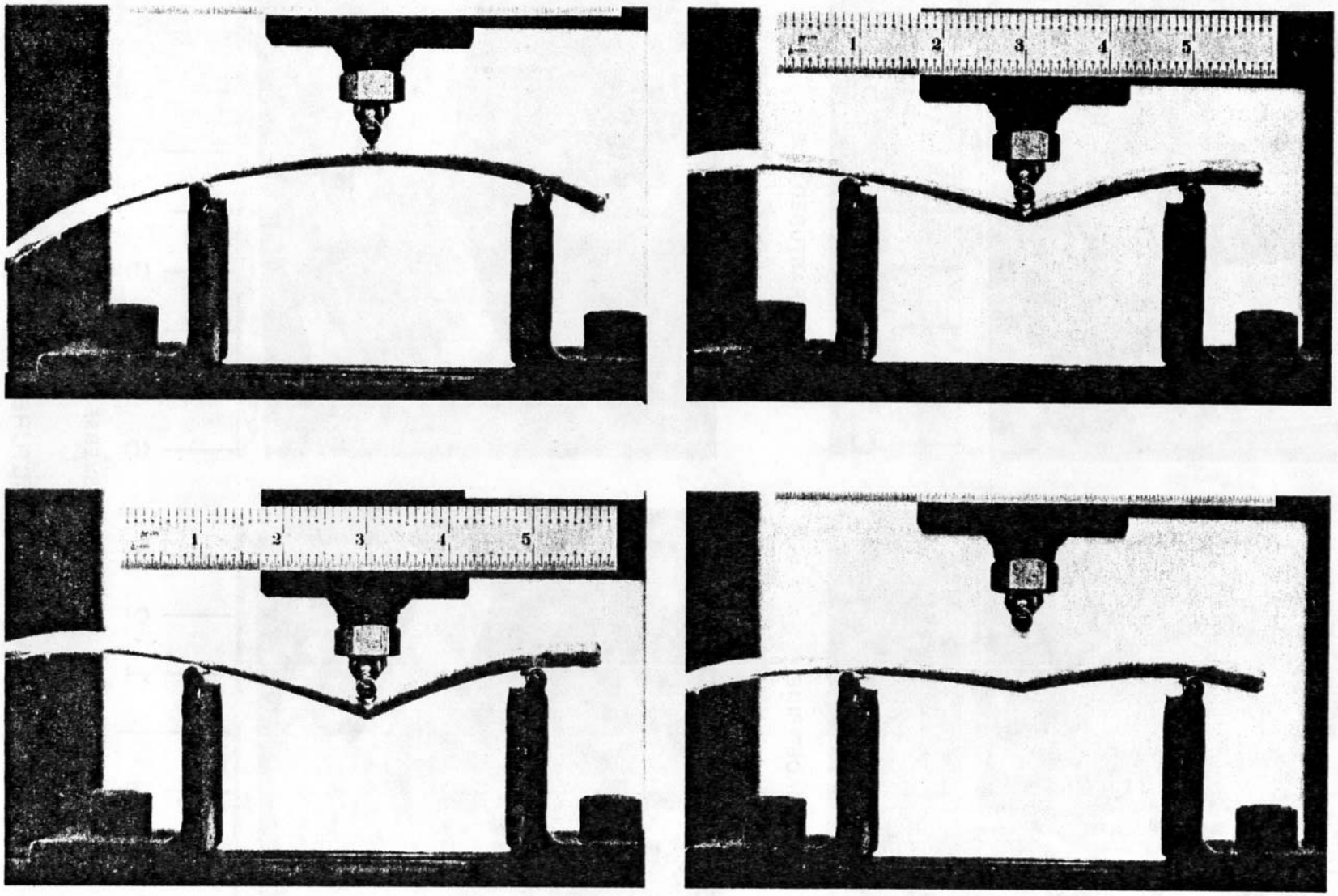
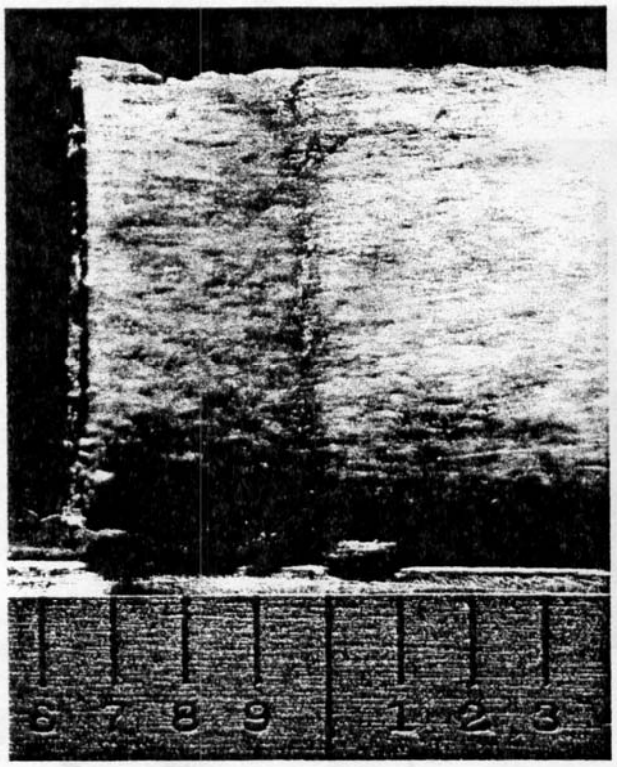
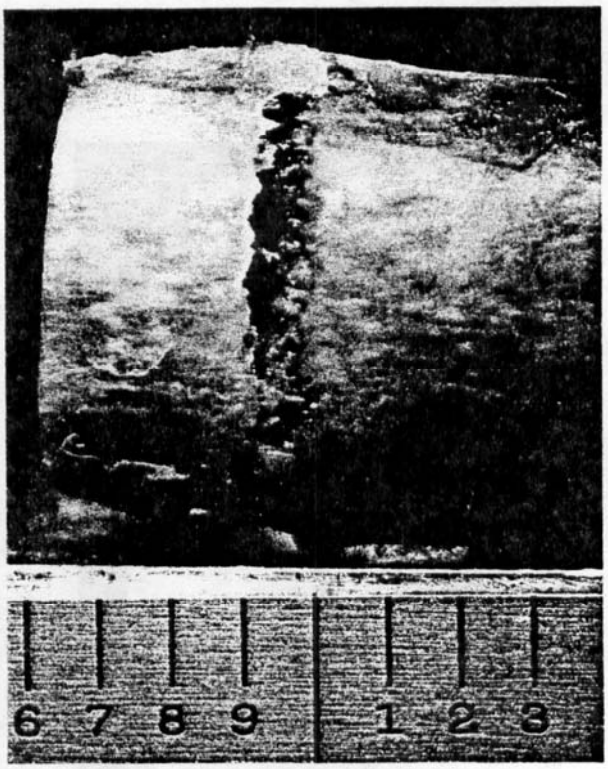


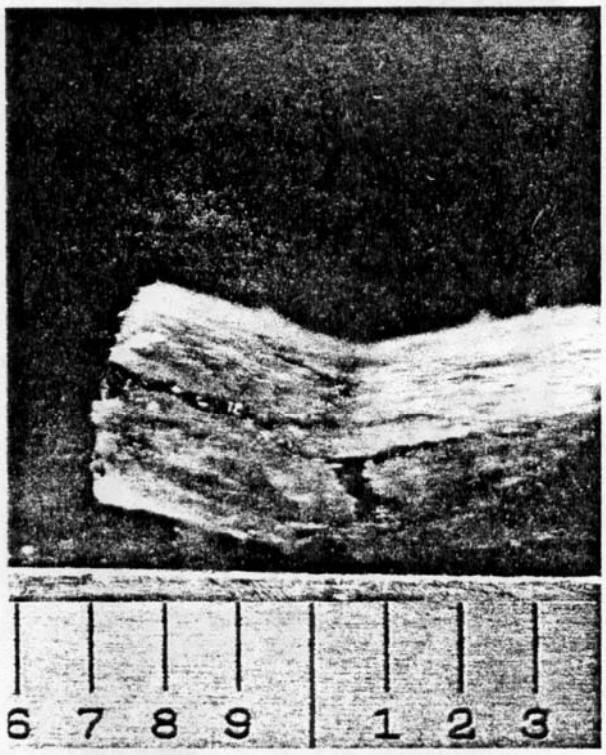
Figure 4 CORTICAL SHELL DEFORMATION



LOADED SIDE

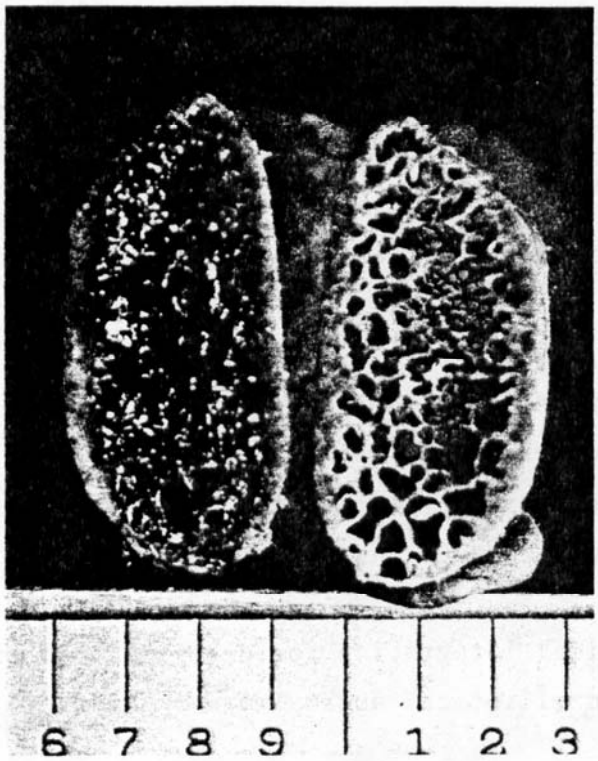


FRACTURED SIDE

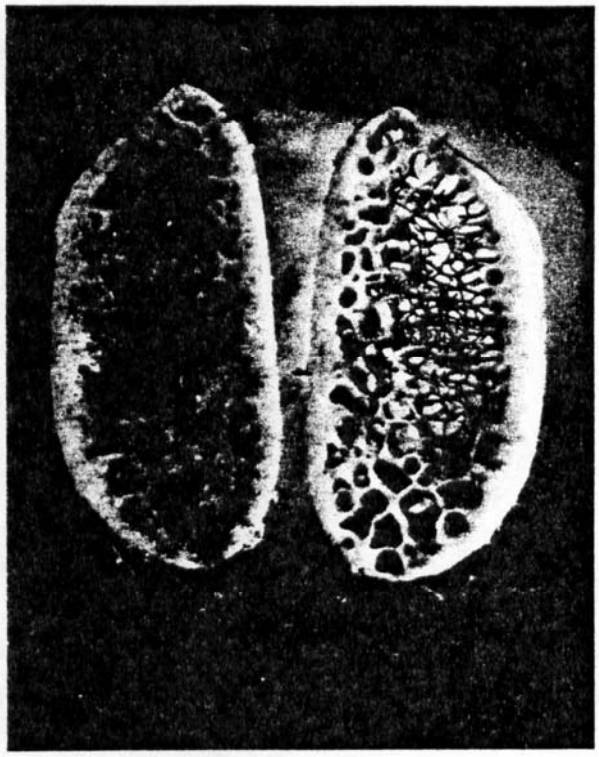


TRANSVERSE

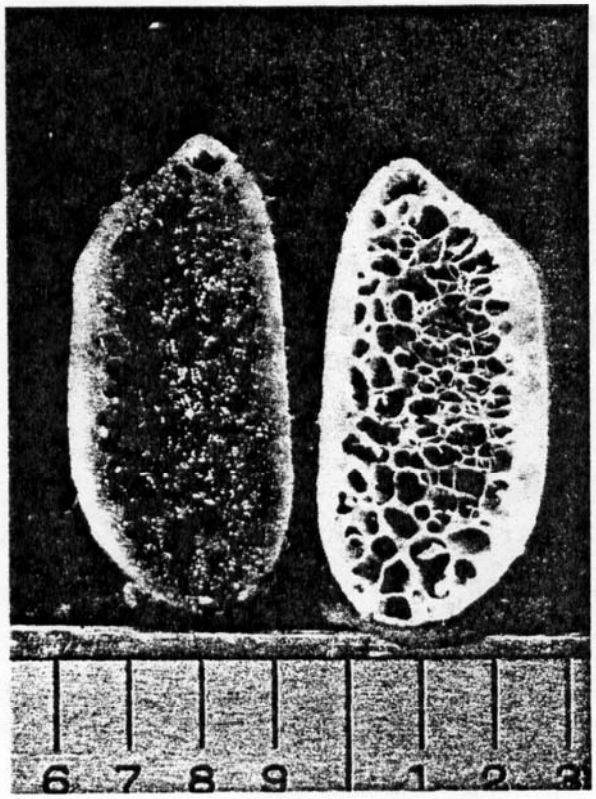
Figure 5 FRACTURE MODE



UNFILTERED ULTRA-VIOLET



FILTERED ULTRAVIOLET



VISIBLE

Figure 6 CLEANED AND UNCLEANED SECTIONS

A ten times enlargement of an image produces considerable problems with grain size in normal photographic materials. Bone sections, reported herein, were photographed on tri-x film with a 3.6X magnification allowing the print to be made with a 2.78 magnification to give the required 10X with minimal grain problems.

The ribs were sectioned at a point as close as possible to the fracture. This does not appear to decrease accuracy since Granik and Stein also reported that the value of the moment of inertia did not vary significantly along the rib. The rib section was cleaned and photographed.

Granik and Stein used a numerical integration for determination of the moment of inertia. In this work, an elliptical approximation was used.

$$I = .7854\,(b_o^3\, a_o - b_i^3\, a_i)$$

where I = moment of inertia

b_o = minor radius of total area (in.)

a_o = major radius of total area (in.)

b_i = minor radius of marrow area (in.)

a_i = major radius of marrow area (in.)

The modulus of elasticity was then calculated using the equation:

$$E = \frac{\Delta P}{\Delta \delta} \cdot \frac{L^3}{48I}$$

where E = Modulus of elasticity (psi)

$\Delta P/\Delta \delta$ = Linear slope force-deflection curve

L = Span length (four inches)

Stress at failure (σ) is determined by the equation:

$$\sigma = \frac{P_u\, Lc}{4I}$$

where P_u = load at breakage (lb.)

c = distance from neutral axis to the most remote point of cross-section (inches)

Data Analysis

Table 4 contains modulus of elasticity and stress at failure for ribs 5, 6 and/or 7 (either right or left) for all subjects.

RESULTS

Results of the four osteologic study techniques performed on the subjects are presented in this section.

Figure 7 is a graph of the percent cortical area (PCA) as a function of age for known normal subjects as presented by Garn et al. Plus and minus one standard deviation lines are also drawn in. PCA values calculated as the average of the right and left femur measurements taken from radiographs and presented in Table 1 are plotted on this figure.

Figure 8 is the same graph with the PCA of the mid shaft (when available) of the subject's radii, the data presented in Table 2 and 5, plotted.

The mid shaft femur and mid shaft radius PCAs are in good agreement for Calman 14, 15, 18 and 19. Calman 16 shows a minus 1 sigma for the femur PCA and a minus 2.8 sigma for the radius PCA, while Calman 17 shows a minus 0.7 sigma for the femur PCA and a plus 1.3 sigma for the radius PCA. As pointed out earlier, evaluation of this type made on the basis of a single x-rays (femur PCAs) is difficult at best. However, a gross evaluation of the relative skeletal quality of these six subjects is obvious from both sets of data. Calman 14, 15, 18 and 19 are near normal, Calman 16 is below normal and Calman 17 is near to above normal. The average of the PCAs for these two techniques (Figure 9) is probably the best representation of the relative skeletal quality of these six subjects. Figure 10 shows the right radius mid shaft sections for Calman 16, 14 and 17 as an example of osteoporotic, average and above average PCA respectively.

TABLE 4

GRANIK AND STEIN RIB TEST DATA

Calman	Rib	$E \times 10^6$	Avg. $E \times 10^6$	$\sigma \times 10^4$	Avg. $\sigma \times 10^4$
6	5	1.72		2.05	
7	5	1.20		1.86	
8	5	1.65	1.34	1.38	1.09
	7	1.03		.80	
9	6	1.79	1.92	2.32	2.47
	7	2.05		2.61	
10	6	1.64	1.89	1.31	1.76
	7	2.13		2.21	
11	5	1.21	1.53	1.24	1.25
	6	1.44		1.30	
	7	1.93		1.21	
12	5	1.16	1.45	1.13	1.66
	6	1.25		1.65	
	7	1.93		2.20	
13	5	1.54	1.66	2.93	2.83
	6	1.82		3.17	
	7	1.63		2.40	
14	5	1.03	1.32	1.10	1.32
	6	1.59		1.62	
	7	1.34		1.24	
15	5	1.50	1.66	1.45	1.72
	6	2.03		2.16	
	7	1.46		1.55	
16	5	.66	.89	1.01	1.26
	6	.86		1.53	
	7	1.15		1.26	
17	5	1.30	1.50	2.14	2.19
	6	1.19		1.97	
	7	2.02		2.47	
18	5	2.16	1.90	2.70	2.16
	6	1.76		1.89	
	7	1.77		1.90	
19	5	1.35	1.33	1.13	1.23
	6	1.35		1.16	
	7	1.28		1.40	

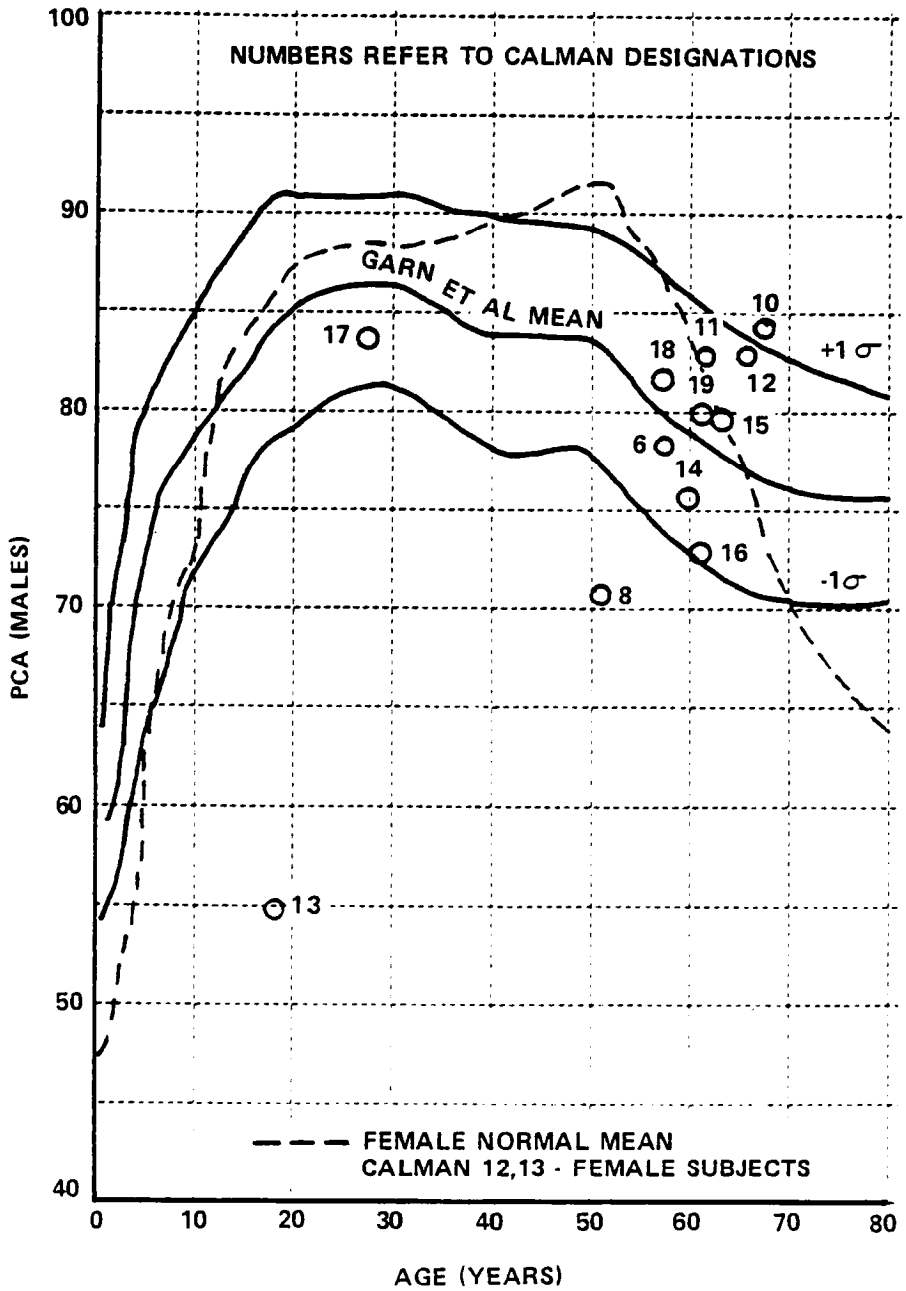


Figure 7 AVERAGE FEMUR MID-SHAFT PCA

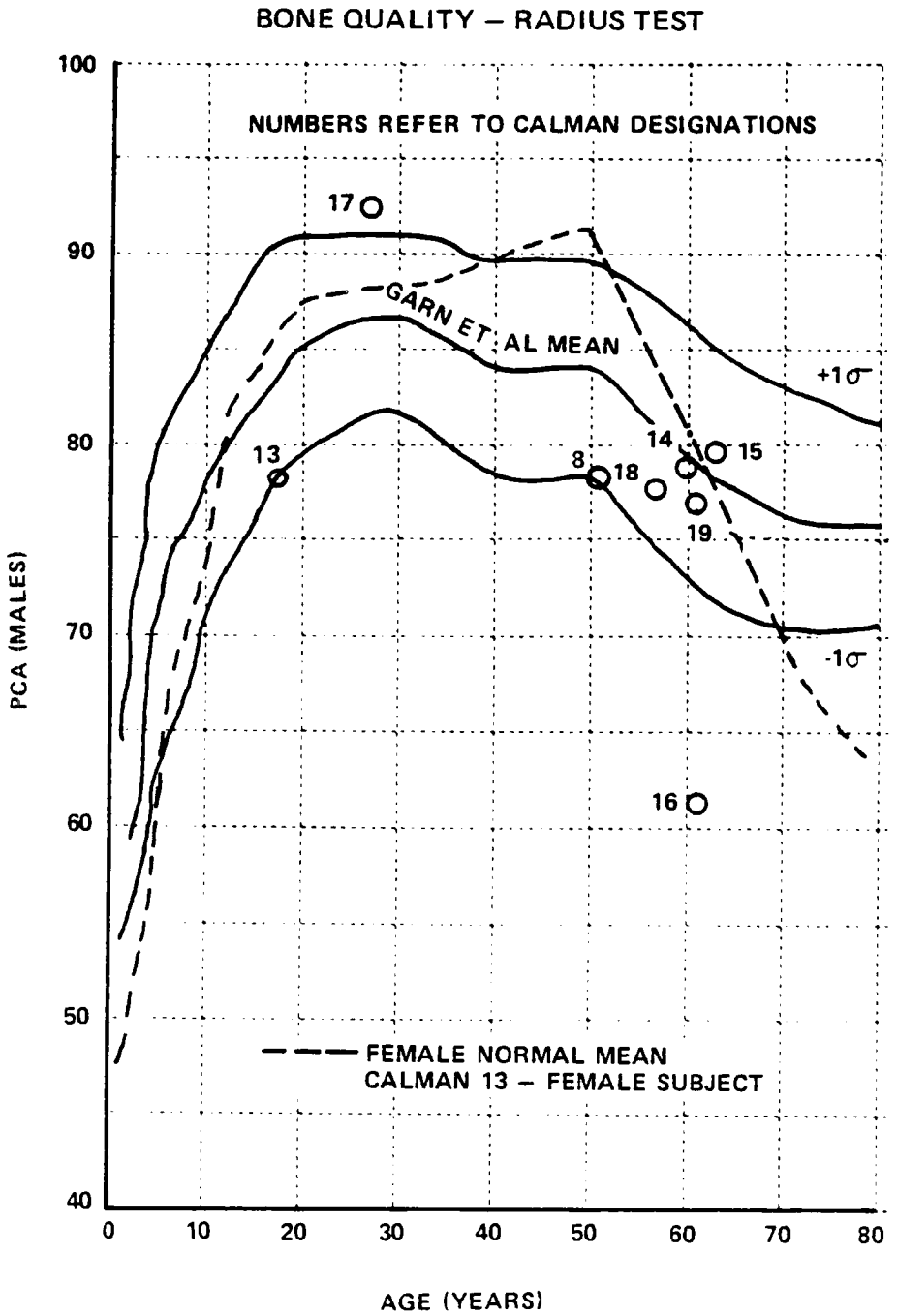


Figure 8 AVERAGE RADIUS MID-SHAFT PCA

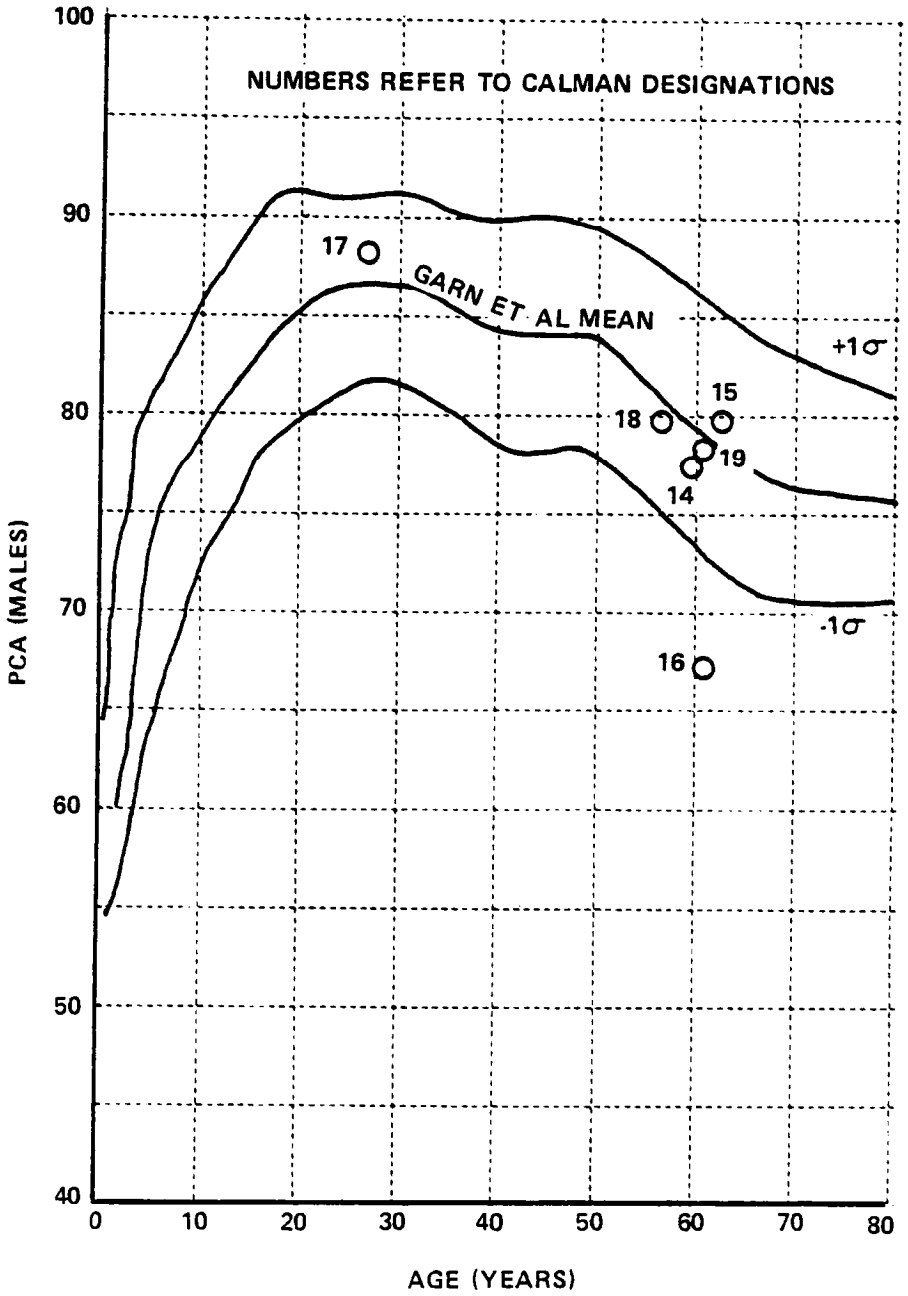
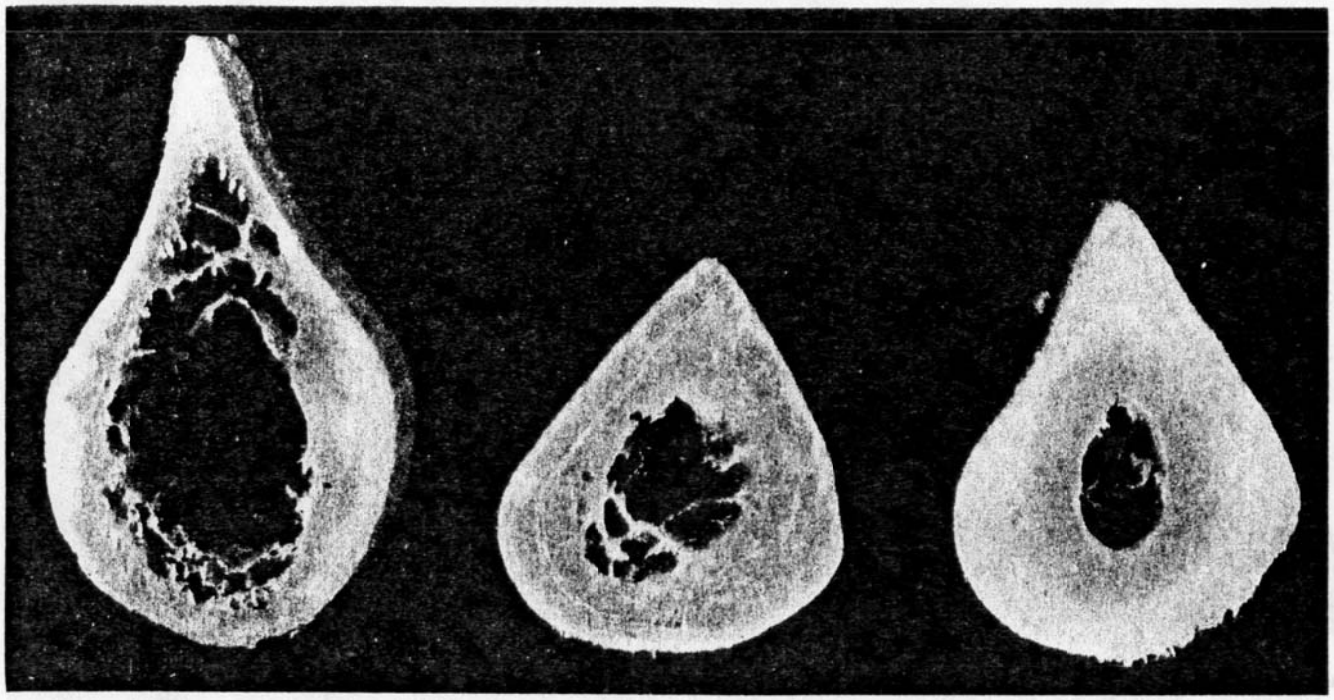


Figure 9 AVERAGE FEMUR & RADIUS MID-SHAFT PCA



CM16	CM14	CM17
PCA = 50.3	PCA = 80.0	PCA = 92.4

RIGHT RADIUS MIDSHAFT

Figure 10 RADIUS COMPARISONS

Referring to Figures 7, average femur mid shaft PCA and 8, average radius mid shaft PCA, it is seen that Calman 13 (a 17 year old female) falls extremely low in the femur test and just under 1 σ in the radius test. Calman 13 was an astrocytoma victim and had spent approximately seven years confined to a wheel chair. Her lumbar spine, pelvis and lower extremities were highly osteoporotic. The ribs and upper extremities showed normal and slightly low ratings respectively. Normally osteoporosis is generalized rather than localized as in this case, therefore, Calman 13 is not included in Figure 9, average femur and radius mid shaft PCA.

While this technique was developed on mid shaft measurement, there is the possibility of not being able to obtain mid shaft data from a radius, as in a case where the radius had been pinned to set a previous fracture. PCAs were also calculated for the proximal and distal ends (just medial to the epiphyses) of the radii. The average of all of these values (Table 2) is presented in Figure 11 and indicates a more conservative evaluation -- lower percent cortical areas.

Table 5 presents the average (left and right) proximal, mid shaft and distal PCAs and shows the percent increase in PCA of the mid shaft with respect to the proximal and distal values. Figure 12 shows the proximal, mid shaft and distal sections of a right radius.

Epker and Frost parabolic index data for normal subjects are presented in Figure 13 along with plus and minus one standard deviation. Plotted on this graph are the average parabolic indices determined from the 5th, 6th and 7th ribs of subjects where these ribs were available. As was the case for the pre-test long bone evaluations, Calman 10 through 15 and 17 through 19 are indicated to be normal to high normal and Calman 16 is indicated to be below normal. Figure 14 shows the cross section of rib number 7 for Calman 16, 14 and 17.

TABLE 5

PCA VALUES

Calman	Radius			Mid shaft % Increase	
	Proximal	Mid shaft	Distal	Proximal	Distal
13	57.13	78.39	68.29	37.2	14.8
14	68.45	78.9	72.65	15.3	8.6
15	66.7	79.7*	71.2	19.5	11.9
16	45.4	61.4	58.4	35.1	5.1
17	76.8*	92.4*	83.8*	20.3	10.2
18	65.95	77.7*	67.0	17.8	16.0
19	64.15	77.0*	68.05	20.0	13.1

*Right radius only.

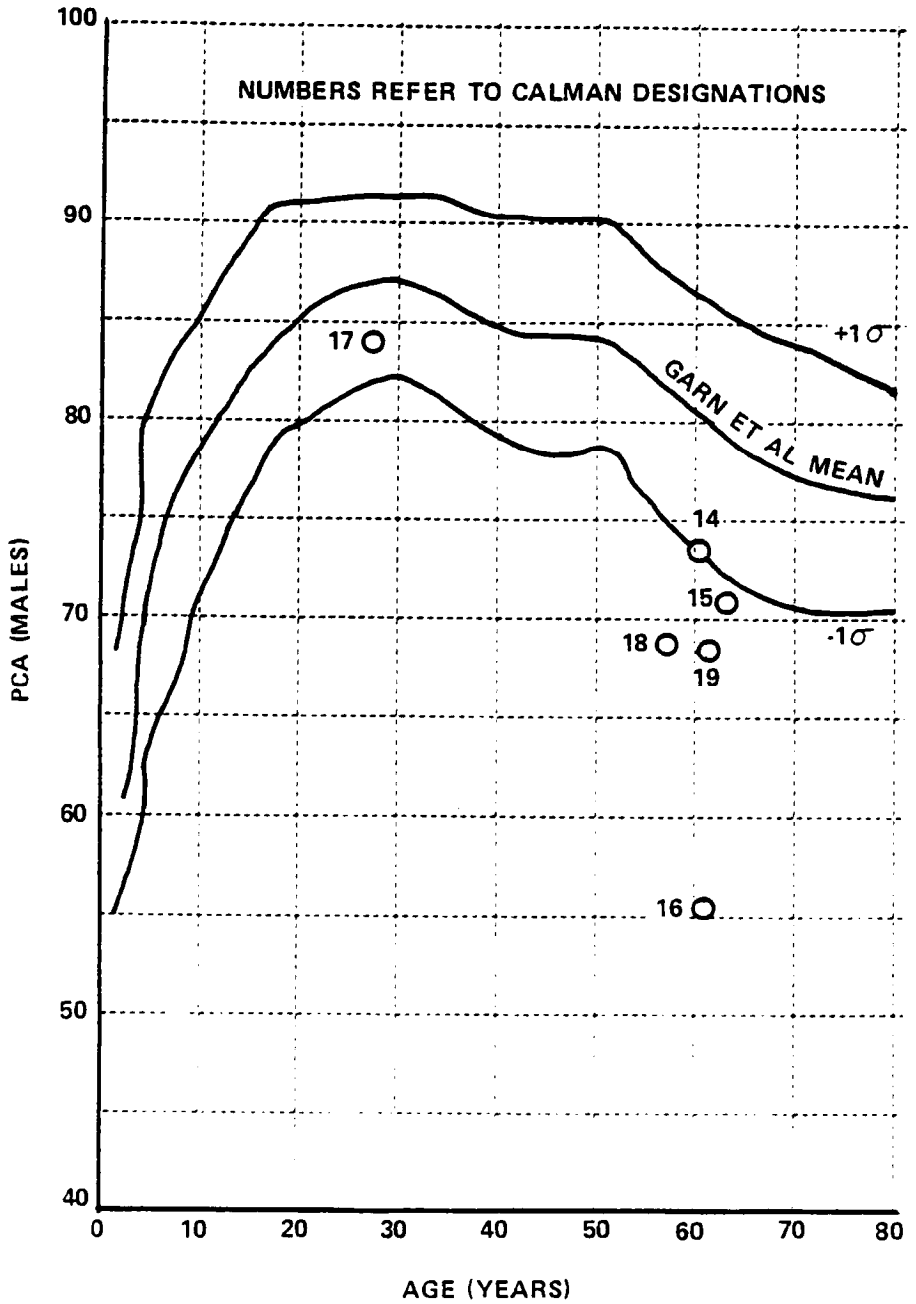
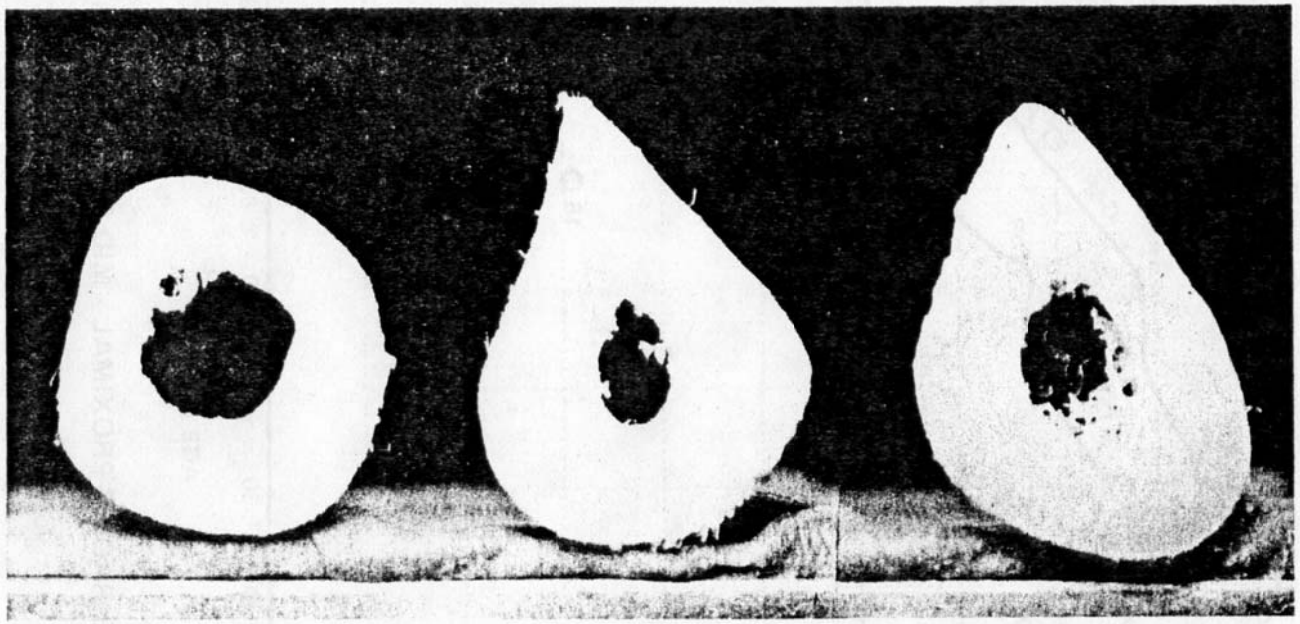


Figure 11 AVERAGE RADIUS PROXIMAL - MID-SHAFT - DISTAL PCA



PROXIMAL MIDSHAFT DISTAL

CALMAN 17 RIGHT RADIUS SECTIONS

Figure 12 RADIUS PROXIMAL, MIDSHAFT, DISTAL COMPARISON

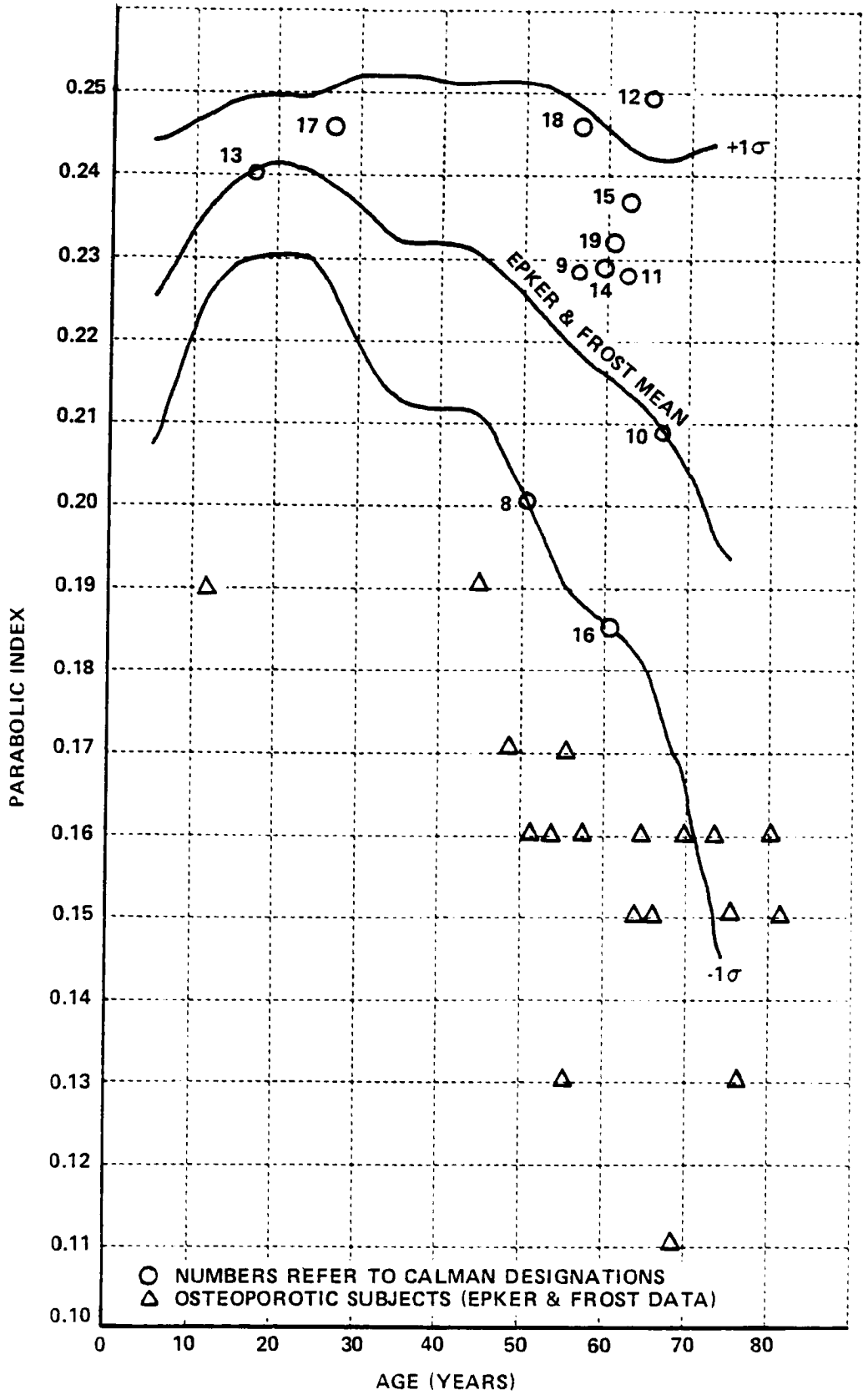
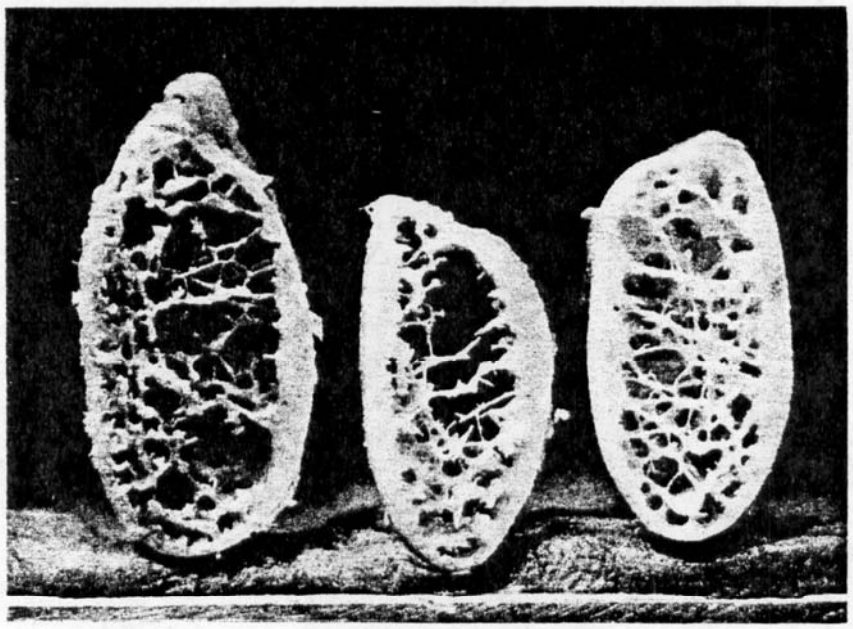


Figure 13 PARABOLIC INDEX AVERAGE OF RIBS 5, 6, 7



CM16	CM14	CM17
PI = .188	PI = .243	PI = .246
$E = 1.15 \times 10^6$	$E = 1.34 \times 10^6$	$E = 2.02 \times 10^6$
$\sigma = 1.26 \times 10^4$	$\sigma = 1.24 \times 10^4$	$\sigma = 2.47 \times 10^4$

RIB NUMBER 7

Figure 14 RIB COMPARISONS

The age normalized parabolic index is presented in Figure 15. There was no standard deviation reported by Epker and Frost for this work. As would be expected, the subject's age normalized parabolic index shows the same relative bone quality delineations.

Granik and Stein did not report the modulus of elasticity nor the stress at failure as a function of age. The values reported for ten normal subjects were $(1.67 \pm 0.31) \times 10^6$ and $(1.54 \pm 0.45) \times 10^4$ repsectively (mean $\pm$ standard deviation). Assuming these values to be independent of age, their mean and standard deviations (S.D.) were drawn and the results of the subject's rib tests performed during this work were plotted (Figures 16 and 17). It is believed that the spread in the data, in part, may be due to inaccuracies associated in determining the moment of inertia of the rib cross sections.

In these figures the modulus and stress at failure are reported as the average values of the subject's 5th, 6th and 7th ribs where they were available. There are wide variations between values obtained from the individual ribs but the averages are better behaved (see Table 4).

The reader is cautioned against making an absolute skeletal quality evaluation from these data since the Granik and Stein technique was standardized on only ten subjects and an elliptical approximation was made for calculation of the moment of inertia in the data reported here.

CONCLUSIONS

(1) All four techniques discussed in this report can be used for determination of the skeletal quality of cadavers.

(2) The pre-crash test techniques described, complement one another and are less subject to observational variability than are the post-test techniques since it is less difficult to define the cortical bone areas in a long bone than it is in a flat bone. Further, the percent cortical area (PCA) technique was standardized on a large population.

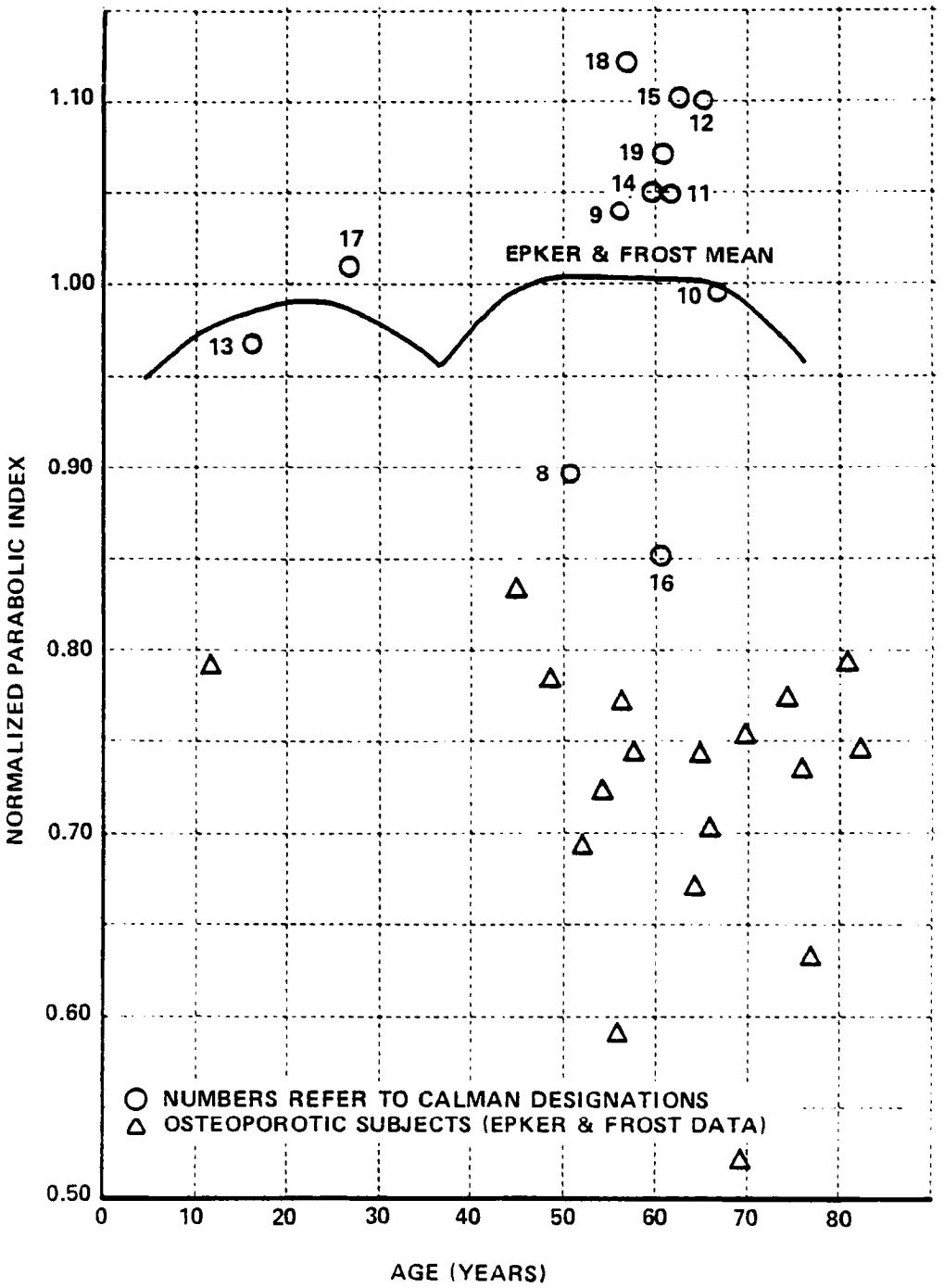


Figure 15 NORMALIZED AGE COMPENSATED PARABOLIC INDEX

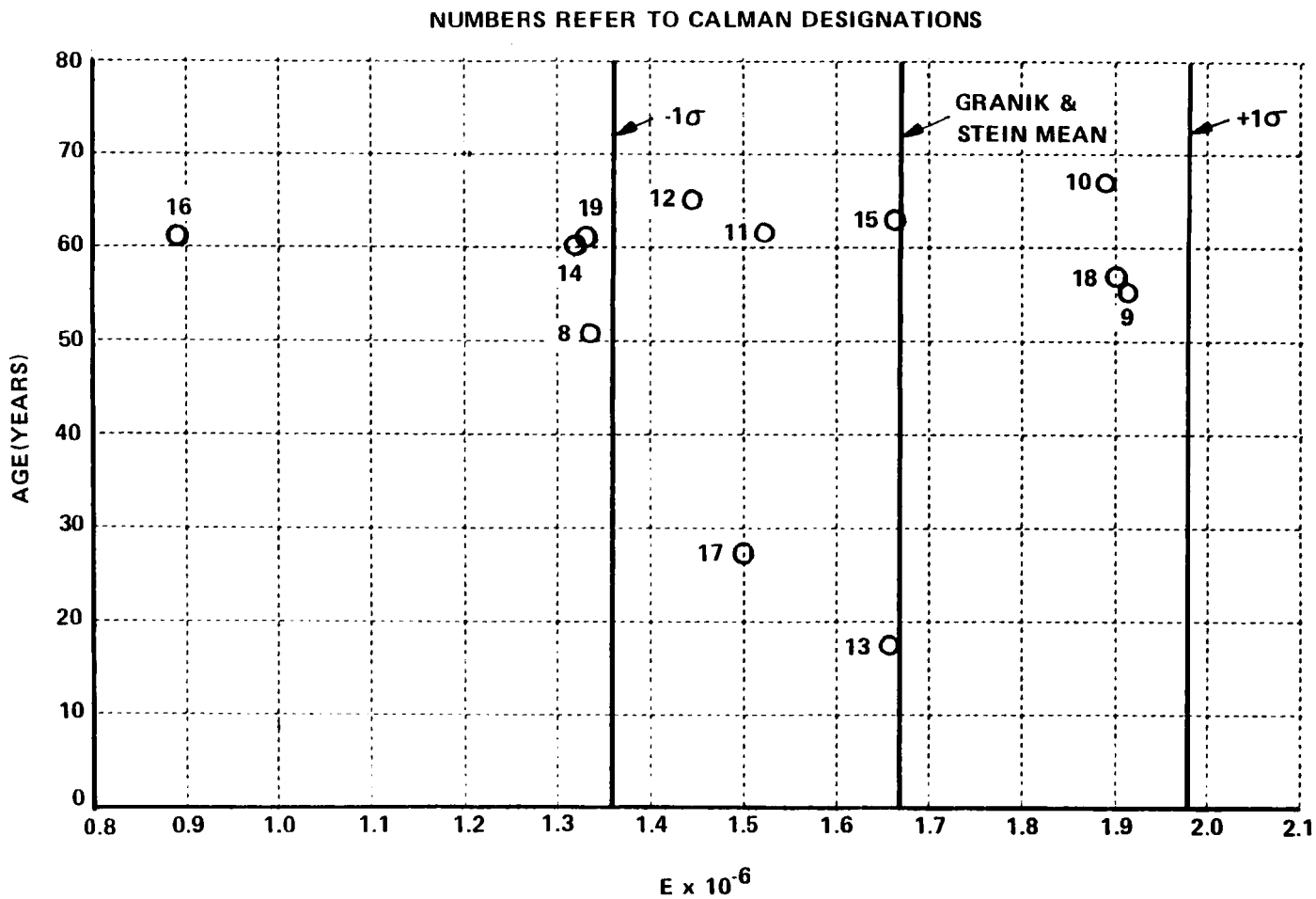


Figure 16 MODULUS OF ELASTICITY AVERAGED OVER RIBS 5, 6, 7

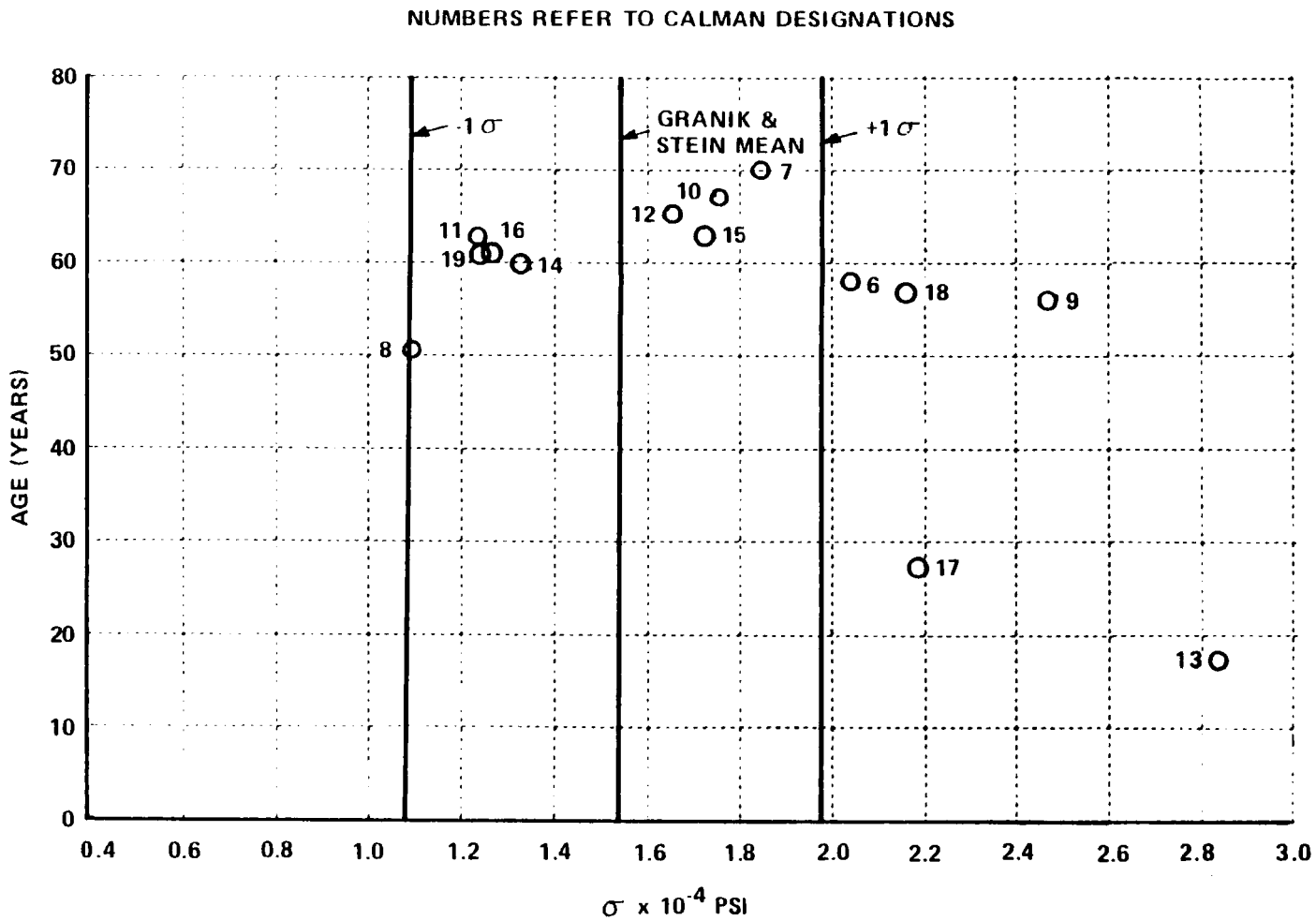


Figure 17 STRESS AT FAILURE AVERAGED OVER RIBS 5, 6, 7

(3) Of the two post-crash test techniques described, the parabolic index appears to be the more reliable skeletal quality criterion since it:

(a) does not require the calculation of the moment of inertia,
(b) was developed for the determination of osteoporsis, and
(c) was standardized on a much larger population than was the modulus and stress at failure technique.

RECOMMENDATIONS

Over the past two years, research and testing laboratories working with cadavers have been performing the Granik and Stein rib tests after impact exposure. Since one of the evaluation steps in this technique is to make an enlargement of the photograph of a rib cross section, it is recommended that these photographs be used to further validate the more operationally simple Epker and Frost technique described in this paper.

It is also recommended that in an effort to further validate the pre-test methods described herein all subsequent cadaver subjects used for impact testing have these techniques performed.

Since it would be of significant aid in comparing cadaver crash testing results with accident investigation findings, it is recommended that consideration be given to the use of one or more of these techniques after the autopsy of victims of an accident fatality.

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(2) Epker, Bruce N. and Frost, Harold M., "The Parabolic Index: A Proposed Index of the Degree of Osteoporosis in Ribs", Journal of Gerontology, Vol. 19, October 1964.

(3) Granik, Gerald and Stein, Ira, "Human Ribs" Static Testing as a Promising Medical Application", Journal of Biomechanics, Vol. 6, No. 3, May 1973.